

# Markscheme

**November 2020**

**Physics**

**Higher level**

**Paper 3**

28 pages

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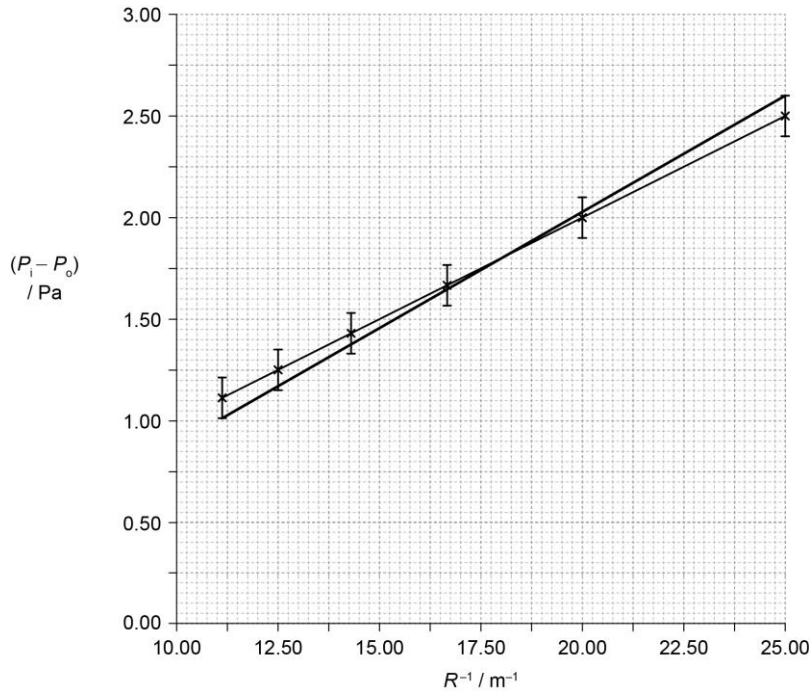
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### Section A

Question			Answers	Notes	Total
1.	a		<p>«theory suggests» <math>P - P_0</math> is proportional to <math>\frac{1}{R}</math> ✓</p> <p>graph/line of best fit is straight/linear «so yes»</p> <p><b>OR</b></p> <p>graph/line of best fit passes through the origin «so yes» ✓</p>	<p><i>MP1: Accept 'linear'</i></p> <p><i>MP2 do not award if there is any contradiction eg: graph not proportional, does not pass through origin.</i></p>	2
1	b	i	<p>gradient = «<math>4\gamma</math>» = 0.10</p> <p><b>OR</b></p> <p>use of equation with coordinates of a point ✓</p> <p><math>\gamma = 0.025</math> ✓</p>	<p><i>MP1 allow gradients in range 0.098 to 0.102</i></p> <p><i>MP2 allow a range 0.024 to 0.026 for <math>\gamma</math></i></p>	2
1	b	ii	<p><math>\text{kg s}^{-2}</math> ✓</p>	<p>Accept <math>\frac{\text{kg}}{\text{s}^2}</math></p>	1

Question			Answers	Notes	Total
1	b	iii	<p>straight line, gradient <b>greater</b> than line of best fit, and within the error bars ✓</p>  <p>The graph plots <math>(P_i - P_o) / \text{Pa}</math> on the y-axis against <math>R^{-1} / \text{m}^{-1}</math> on the x-axis. The y-axis scale is from 0.00 to 3.00 in increments of 0.50. The x-axis scale is from 10.00 to 25.00 in increments of 2.50. Six data points are plotted with vertical error bars. A solid line represents the line of best fit. A second straight line is drawn, which is steeper than the line of best fit and passes through the first and last data points.</p>		1

Question			Answers	Notes	Total
1	b	iv	<p>«15% of 0.025» = 0.00375</p> <p><b>OR</b></p> <p>«15% of 0.030» = 0.0045 ✓</p> <p>rounds uncertainty to 1sf</p> <p>±0.004</p> <p><b>OR</b></p> <p>±0.005 ✓</p>	<p><i>Allow ECF from (b)(i)</i></p> <p><i>Award [2] marks for a bald correct answer</i></p>	2
1	b	v	<p>Experimental value matches this/correct, as expected value within the range ✓</p> <p><b>OR</b></p> <p>experimental value does not match/incorrect, as it is not within range ✓</p>		1

Question			Answers	Notes	Total
2.	a		<p>In order to draw a graph« of <math>W</math> versus <math>\frac{1}{T^2}</math> »</p> <p><b>OR</b></p> <p>to confirm proportionality between «<math>W</math> and <math>T^{-2}</math> »</p> <p><b>OR</b></p> <p>to confirm relationship between «<math>W</math> and <math>T</math> »</p> <p><b>OR</b></p> <p>because <math>W</math> is the independent variable in the experiment ✓</p>	OWTTE.	1
2	b		<p><b>ALTERNATIVE 1</b></p> <p><math>W + \text{friction} = \frac{4\pi^2 mr}{T^2}</math></p> <p><b>OR</b></p> <p>centripetal force is larger «than <math>W</math>» / <math>W</math> is smaller «than centripetal» ✓</p> <p>«so» experimental <math>mr</math> is smaller «than calculated value» ✓</p> <p><b>ALTERNATIVE 2</b> (refers to graph)</p> <p>reference to «friction force is» a systematic error «and does not affect gradient» ✓</p> <p>«so» <math>mr</math> is the same ✓</p>	<p><i>MP2 awarded only with correct justification. Candidates can gain zero, MP1 alone or full marks.</i></p> <p>OWTTE</p>	2

Question			Answers	Notes	Total
2	c	i	mention of mean/average value «of $T$ » ✓  this reduces uncertainty in $T$ / result  <b>OR</b>  more accurate/precise ✓	<i>Reference to “random errors average out” scores MP1</i>  <i>Accept “closer to true value”, “more reliable value” OWTTE for MP2</i>	2
2	c	ii	systematic errors «usually» constant/always present/not influenced by repetition ✓	OWTTE	1

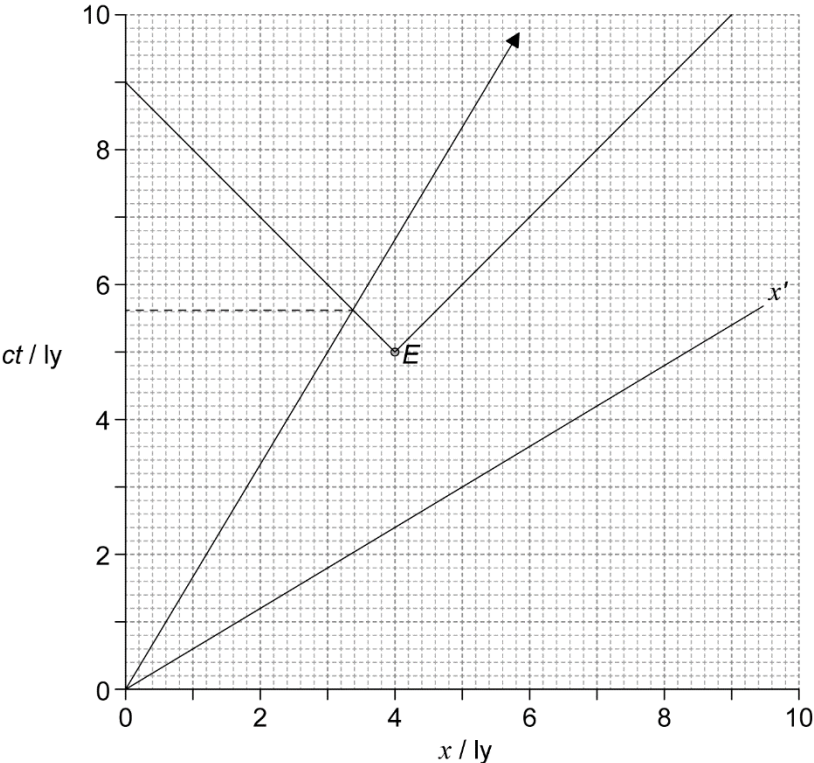
## Section B

### Option A — Relativity

Question			Answers	Notes	Total
3.	a		mention of electric <b>AND</b> magnetic fields ✓ <b>OR</b> mention of electromagnetic radiation/wave/fields ✓		1
3	b		the laws of physics are the same in all «inertial» frames of reference/for all «inertial» observers ✓	OWTTE	1
3	c	i	magnetic ✓		1
3	c	ii	«In observer frame» protons «in the two wires» move in same/parallel direction ✓ these moving protons produce magnetic attraction ✓ there is also a smaller electrostatic repulsion due to wires appearing positive due to length contraction «of proton spacing» ✓	OWTTE	3



Question			Answers	Notes	Total
4.	a		constancy of time <b>OR</b> speed of light > c is possible ✓	OWTTE.	1
4	b	i	$\gamma = 1.15$ ✓ length = 6.9 «m» ✓	Allow length in the range 6.7 to 7.0 m.  Allow ECF from wrong $\gamma$  Award <b>[2]</b> marks for a bald correct answer in the range indicated above.	2
4	b	ii	8.0 m / measurement made on the probe ✓ the measurement made by an observer at rest in the frame of the probe ✓		2
4	c		$u = \frac{0.5c + 0.8c}{1 + \frac{0.5c \times 0.8c}{c^2}} \quad \checkmark$ $u = 0.93c$ ✓	Allow <b>all</b> negative signs for velocities  Award <b>[2]</b> marks for a bald correct answer	2

Question			Answers	Notes	Total
5.	a	i	0.6c ✓	Accept $1.8 \times 10^8 \text{ ms}^{-1}$ if unit given.	1
5	a	ii	<p>line through origin and through (5, 3) ± one small square at this coordinate ✓</p> 	Answers shown for 5(a)(ii) and (b)(i) and (b)(ii).	1
5	b	i	<p>X value of E at 4 «ly» ✓</p> <p>Y value of E at 5 «y» ✓</p>		2

(continued...)

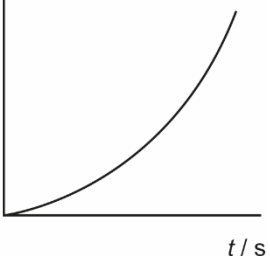
(Question 5 continued)

Question			Answers	Notes	Total
5.	b	ii	light cone from E «crosses $ct$ at 9 so» intersection on $ct = 5.6 \pm 0.2$ y «on $ct$ scale» ✓ $\gamma = 1.25$ ✓ so $t = \frac{5.6}{1.25} = 4.5$ «y after leaving Earth» ✓	MP1 accept use of linear equations to find $t = 5.625$ Allow ECF from (b)(i) and (a)	3

6.	a		invariant mass <b>OR</b> mass of object when not in motion/in object's rest frame ✓		1
6	b		«rest energy =» $(2.014 \times 931.5)$ «MeV» ✓ « $E_T = KE + \text{rest energy} = 270.0 + (2.014 \times 931.5) = 2146$ «MeV» ✓	Final answer accept $3.443 \times 10^{-10} \text{ J}$ if unit given Award <b>[2]</b> marks for a bald correct answer.	2
6	c		is converted to energy ✓ as kinetic energy of the products ✓		2

Question			Answers	Notes	Total
7.	a		« $\frac{\Delta f}{f} = \frac{g\Delta h}{c^2} = \frac{9.81 \times 22.6}{c^2}$ » $\frac{\Delta f}{f} = 2.46 \times 10^{-15}$ ✓		1
7	b	i	GPE gained by photons so $E$ increases ✓ $E = hf$ , so frequency increases ✓		2
7	b	ii	gamma rays travel at $c$ ✓ detector accelerates towards source so «by Doppler effect» $\lambda$ reduced so frequency increases ✓	Award <b>[1 max]</b> for reference to principle of equivalence without further explanation.	2

Option B — Engineering

Question			Answers	Notes	Total
8.	a		$\omega_f^2 = 0 + 2 \times 0.110 \times 6 \times 2\pi \checkmark$ $\omega_f = 2.88 \text{ «rad s}^{-1}\text{»} \checkmark$	Other methods are possible. At least 2 sig figs for MP2.	2
8	b		concave up from origin $\checkmark$ $\theta / \text{rad}$  $t / \text{s}$		1
8	c		$\Gamma \propto I \alpha$ so $\Gamma = 0.110 \times 0.0216 \Rightarrow 2.38 \times 10^{-3} \text{ «N m»} \checkmark$		1
8	d		$\alpha = \frac{2.9^2}{2 \times 2\pi \times 30} = \text{OR } -0.022 \text{ «rad s}^{-2}\text{»} \checkmark$ $t \ll \frac{\omega_f - \omega_i}{\alpha} = \frac{-2.9}{-0.0220} \gg 130 \text{ «s»} \checkmark$	Other methods are possible. Award [2] marks for a bald correct answer	2

Question			Answers	Notes	Total
9.	a		<p>«person rotates» anticlockwise ✓</p> <p>the person gains angular momentum «in the opposite direction to the new wheel motion» ✓</p> <p>so that the total angular momentum is conserved ✓</p>	<p>OWTTE</p> <p>Award <b>[1 max]</b> for a bald statement of conservation of angular momentum.</p>	3
9	b		<p>the rotational kinetic energy has increased ✓</p> <p>energy is provided by the person doing work «flipping the wheel» ✓</p>	OWTTE	2

10.			<p>conservation of rotational and linear energy</p> <p><b>OR</b></p> $mgh = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2 \quad \checkmark$ <p>using <math>I = \frac{2}{5}mr^2</math> <b>AND</b> <math>\omega = \frac{v}{r}</math> ✓</p> <p>with <b>correct manipulation</b> to find the requested relationship ✓</p>		3
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Question			Answers	Notes	Total
11.	a	i	«–» $3 \times 10^3$ «J» ✓		1
11	a	ii	0 «J» ✓	OWTTE	1
11	b	i	use of $PV^{\frac{5}{3}}$ is constant « $4.0 \times 10^5 \times (2.0 \times 10^{-2})^{\frac{5}{3}} = P_2 \times (5.0 \times 10^{-2})^{\frac{5}{3}}$ » ✓  $P_2 = 8.7 \times 10^4$ «Pa» <b>OR</b> 87 «kPa» ✓	Award <b>[2]</b> marks for a bald correct answer	2
11	b	ii	adiabatic means no transfer of heat in or out of the system ✓  should be fast ✓  «can be slow if» the system is insulated ✓	OWTTE	2 max

Question			Answers	Notes	Total
12.	a		incompressible ✓ non-viscous ✓ laminar/streamlined flow ✓		2 max
12	b		radius of sphere = $0.012 \text{ «m»}$ ✓  weight of sphere = $6\pi\eta rv + \rho Vg$  <b>OR</b>  $v = \frac{(1.26 \times 10^{-2} - 915 \times 7.24 \times 10^{-6}) \times 9.81}{6\pi \times 37.9 \times 10^{-3} \times 1.2 \times 10^{-2}} \checkmark$  $v = 6.84 \text{ «m s}^{-1}\text{»}$ ✓	Accept use of $g = 10$ leading to $v = 7.0 \text{ «m s}^{-1}\text{»}$  Allow implicit calculation of radius for MP1  Do not allow ECF for MP3 if buoyant force omitted.	3

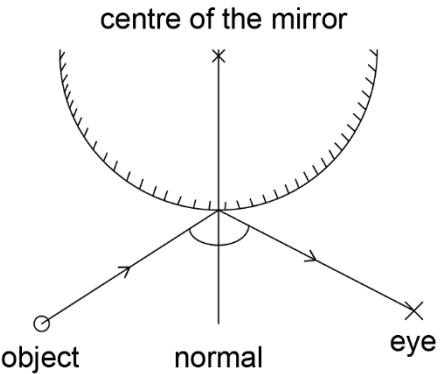
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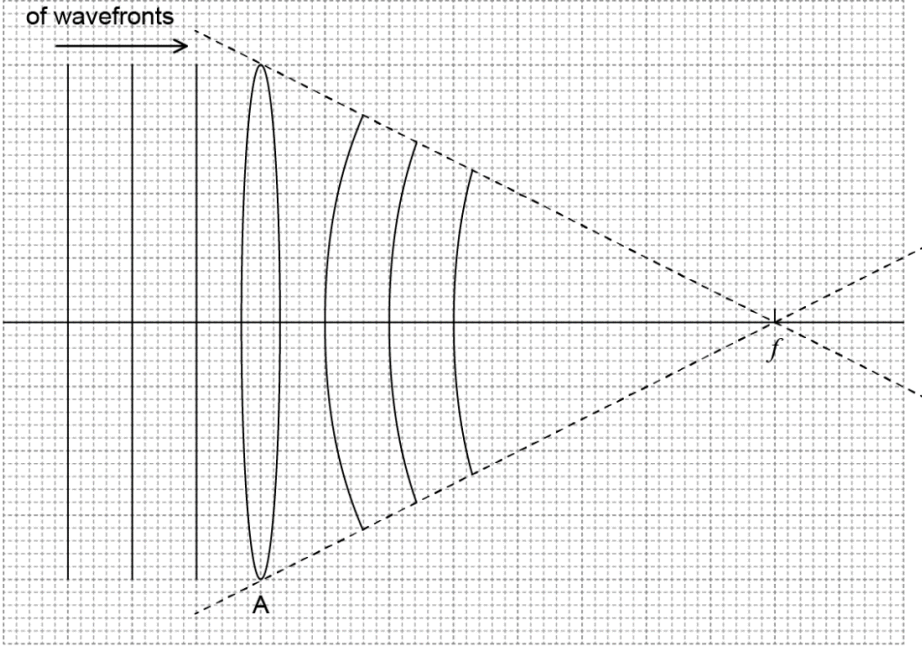


(Question 12 continued)

Question			Answers	Notes	Total
12.	c	i	$F = mg - \rho Vg$ <b>OR</b> $F = (0.0126 \times 9.81) - (915 \times 7.24 \times 10^{-6} \times 9.81) \checkmark$ $F = 5.86 \times 10^{-2} \text{ «N» } \checkmark$	Accept use of $g = 10$ leading to $F = 6.0 \times 10^{-2} \text{ N}$	2
12	c	ii	$Q = \ll 2\pi \times \frac{\text{energy stored}}{\text{energy lost}} = 2\pi \times \frac{100}{10} = \gg 63 \checkmark$		1
12	c	iii	drag force increases <b>OR</b> damping increases <b>OR</b> more energy lost per cycle $\checkmark$ Q will decrease $\checkmark$		2

Option C — Imaging

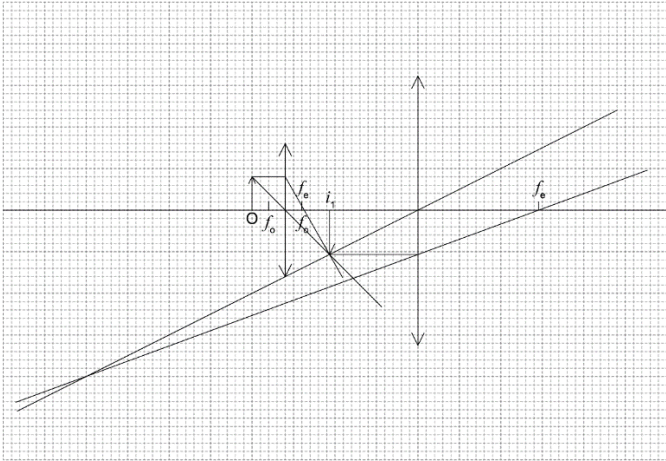
Question			Answers	Notes	Total
13.	a		<p>attempt to connect object and eye with ray showing equal angles of reflection such that reflection occurs within 1 hatch mark of position shown ✓</p> <p>construction showing normal at point of reflection ✓</p>  <p>object      normal      eye</p>	<p><i>Allow rays that are drawn freehand without a ruler - use judgement.</i></p>	2
13	b		<p>light rays do not pass through the image</p> <p><b>OR</b></p> <p>do not form an image on a screen</p> <p><b>OR</b></p> <p>appear to have come from a point</p> <p><b>OR</b></p> <p>formed by extension of rays ✓</p>	OWTTE.	1

Question	Answers	Notes	Total
14. a	<p>wavefront separation identical and equal to separation before the lens ✓</p> <p>wavefronts converging, approximately centered on <math>f</math> ✓</p> <p>direction of travel of wavefronts</p> 	<p>By eye.</p> <p>Dotted construction lines are not required, allow wavefronts to extend beyond or be inside the dotted lines here.</p> <p>Allow <b>[1max]</b> if only two wavefronts drawn.</p>	2
14 b	$\frac{1}{v} = \frac{1}{4.00} - \frac{1}{4.50} \quad \checkmark$ $v = 36.0 \text{ «cm»} \quad \checkmark$		2

(continued...)

(Question 14 continued)

Question			Answers	Notes	Total
14.	c		$A: \frac{1}{-2.0} = \frac{1}{8} + \frac{1}{u} \checkmark$ $u = -1.6 \text{ «cm» } \checkmark$ $\text{distance necessary} = \text{«36.0–1.6 =» } 34.4 \text{ «cm» } \checkmark$	<p>Allow <b>[2 max]</b> for ECF for no negative in MP1. Gives <math>u=2.7</math> and distance of 38.7«cm»</p> <p>Allow ECF from (b) in MP3.EG use of 0.4m / 40cm.</p>	3
14	d		$\text{« } m = -\frac{i}{o} = \frac{-36}{4.5} \text{ for A or } \frac{-8}{-1.6} \text{ for B »}$ $m_A = \text{«–» } 8 \textbf{ OR } m_B = \text{«+» } 5 \checkmark$ $\text{total magnification} = \text{«–» } 40 \checkmark$	<p>Allow <b>[2]</b> marks for a bald correct answer</p> <p>Allow ECF from (b) and (c).</p> <p>Eg if <math>u=2.7\text{cm}</math> in (c) then <math>m_B = 3</math> and total <math>m=24</math></p>	2

Question			Answers	Notes	Total
15.	a		the final image lies at the near point «often assumed to be 25 cm» ✓		1
15	b		<p>any 2 correct rays from O for objective lens ✓</p> <p>forming an intermediate image at approximate position shown</p> <p><b>OR</b></p> <p>use of image from objective lens as object for eyepiece lens ✓</p> <p>any 2 correct rays for eyepiece lens from intermediate image ✓</p> <p>ray extension to form a final image ✓</p> 	<p><i>Allow ECF for MP2, MP3 &amp; MP4 for badly drawn rays.</i></p> <p><i>MP4 allow final image to be off the page</i></p>	4

Question			Answers	Notes	Total
16.			mention of attenuation ✓ mention of dispersion or pulse broadening ✓ gives explanation for at least one of above ✓		3
17.	a		bone «denser so» absorb rays «and appear white in the negative» ✓ larger attenuation for bone ✓ muscles have less attenuation, so rays pass through «and appear darker» ✓	<i>Accept the reversed argument</i>	3
17	b		collimation✓ fluorescent screens «each side of photographic plate» ✓ barium/magnesium meal ✓		1 max

Question			Answers	Notes	Total
18.	a		use of strong magnetic field ✓ protons are aligned ✓ radio wave at «nuclear» resonant frequency flips «some of» them into higher energy state ✓ proton de-excites emitting energy at known «radio» wavelength/frequency/Larmor frequency ✓ «which can be located and detected»		3 max
18	b		mention of gradient field «added to the NMR uniform magnetic field» ✓ reference to «the total field that determines» the output «Larmor» frequency from the de-excitation ✓ different positions «in the body» give rise to different frequencies ✓ «and this can be mapped»		2 max
18	c		NMR higher resolution ✓ NMR less attenuation ✓	<i>Accept the reverse argument</i>	1 max

**Option D — Astrophysics**

Question			Answers	Notes	Total
19.	a		AU: «average» distance from the Earth to the Sun ✓ ly: distance light travels in one year ✓		2
19	b	i	made of ice «and dust» ✓ «highly» eccentric/elliptical orbit around the Sun ✓ formed in the Oort Cloud ✓		1 max
19	b	ii	star / named star / stellar cluster/ galaxy/ constellation ✓	Answer may be indicated on the photograph.	1
20.	a		substitution of $L = \sigma AT^4$ into $b = \frac{L}{4\pi d^2}$ giving $b = \frac{\sigma AT^4}{4\pi d^2}$ ✓	Removal of constants $\sigma$ and $4\pi$ is optional	1
20	b		equation applies to Sirius/stars that are luminous/emit light «from fusion» ✓ but Venus reflects the Sun's light/does not emit light «from fusion» ✓	OWTTE	2



Question			Answers	Notes	Total
21.	a		$\ll \frac{R_0}{R} = \gg$ $\frac{1}{1.11}$ <b>OR</b> 0.90 <b>OR</b> 90% ✓		1
21	b		<p>«Hubble's » measure of v/recessional speed uses redshift which is z</p> <p><b>OR</b></p> <p>redshift (z) of galaxies is proportional to distance «from earth»</p> <p><b>OR</b></p> <p>combines <math>v = Hd</math> <b>AND</b> <math>z = \frac{v}{c}</math> into one expression, e.g. <math>z = \frac{Hd}{c}</math> ✓</p>	OWTTE	1
21	c		<p>reference to «redshift due to» expansion of the universe, «not recessional speed» ✓</p> <p>expansion of universe stretches spacetime / increases distance between objects ✓</p> <p>«so» wavelength stretches / increases leading to observed redshift ✓</p>		3

Question			Answers	Notes	Total
22.	a		$\left\langle \frac{L}{L_{\odot}} = \frac{M^{3.5}}{M_{\odot}^{3.5}} = 5.70^{3.5} = \right\rangle 442 \checkmark$ <p>the luminosity of Eta (<math>2630 L_{\odot}</math>) is very different «so it is not main sequence» <math>\checkmark</math></p>	<p>Allow calculation of <math>L^{\frac{1}{3.5}}</math> to give <math>M = 9.5 M_{\odot}</math> so not main sequence</p> <p>OWTTE</p>	2
22	b	i	$d \left\langle = \frac{1}{2.36 \times 10^{-3}} \right\rangle = 424 \text{ «pc»} \checkmark$		1
22	b	ii	<p>Use of <math>d = \sqrt{\frac{L}{4\pi b}} \checkmark</math></p> $= \sqrt{\frac{2630 \times 3.83 \times 10^{26}}{4\pi \times 7.20 \times 10^{-10}}} \checkmark$ $\left\langle = \frac{1.055 \times 10^{19}}{3.26 \times 9.46 \times 10^{15}} \right\rangle = 342 \text{ «pc»} \checkmark ($	<p>Award <b>[3]</b> marks for a bald correct answer between 340 and 344 «pc»</p>	3

(continued...)

(Question 22 continued)

Question			Answers	Notes	Total
22.	c		parallax angle in milliarc seconds/very small/at the limits of measurement ✓ uncertainties/error in measuring $L$ or $b$ or $\theta$ ✓ values same order of magnitude, so not significantly different ✓	Accept answers where MP1 and MP2 both refer to parallax angle OWTTE	2 max
22	d		reference to change in size ✓ reference to change in temperature ✓ reference to periodicity of the process ✓ reference to transparency / opaqueness ✓		3 max
22	e		shorter time ✓  star more massive and mass related to luminosity <b>OR</b> star more massive and mass related to time in main sequence <b>OR</b> position on HR diagram to the left and above shows that will reach red giant region sooner ✓		2

Question			Answers	Notes	Total
23.			higher atomic number than iron ✓ excess of neutrons ✓ radioactive/undergoing beta decay ✓	<i>Allow heavier than iron for MP1</i>	2 max

24	a		the temperature/«peak» wavelength/intensity «of the CMBR» varies «slightly» / is not constant in different directions ✓		1
	b		quantum fluctuations «that have expanded» ✓ density perturbations «that resulted in galaxies and clusters of galaxies» ✓ dipole distortion «due to the motion of the Earth» ✓		2 max